NISTAR Quality Report

Version 1

June 28th, 2016

James Briscoe

L-1 Standards and Technology

Steven Lorenz

L-1 Standards and Technology

Goddard Space Flight Center
Greenbelt, Maryland

National Aeronautics and Space Administration

1 NISTAR QUALITY REPORT

This report is written to describe the various issues and concerns which remain for NISTAR Level 1 data which users should be aware of.

I. VC0 / VC1 DATA RATE SWITCHES

When the spacecraft is in real time contact with the ground, data is generated at the maximum data rate. This data is said to be made available through Virtual Channel 0 (VC0). The data rate is 1 Hz (one data packet per second) for Science data (AppID 82) and Miscellaneous data (AppID Misc), 0.1 Hz for Engineering data (AppID 86), and 1/30 Hz for Thermistor data (AppID 37). When the spacecraft is on the back orbit, the data is filtered to preserve onboard memory storage and downlinked at the start of the next contact. This data is transmitted through Virtual Channel 1 (VC1). VC1 data is available during real time contacts as well, but is duplicated within the VC0 data. The VC1 data is filtered to 1/6th of the nominal cadence, i.e. 1/6 Hz for Science data, etc. The issue is most critical during winter months when there is less visibility of the spacecraft from the Northern Hemisphere ground stations, and therefore less availability of VC0 data. When DSCOVR becomes the primary operational solar weather spacecraft (replacing ACE) and receives 24 hour ground support, this will no longer be an issue and VC0 data will be always available. Transition from ACE to DSCOVR is planned for June 28th, 2016.

For data prior to ACE-DSCOVR transition, the lack of VC0 data presents an issue for post processing of the data. When the shutter is in autocycle on mode (oscillates between open and closed with a fixed period), the demodulation (amplitude extraction) of the radiometer power signal relies on an accurate knowledge of the number of samples per shutter cycle. The period of the shutter motions is computed via a Fourier analysis of the input power signal. If the number of samples per cycle changes during a day of processing the demodulation will lose accuracy and usefulness. The switches between VC0 and VC1 data rate (Figure 1) cause such a problem unless the data is treated carefully.

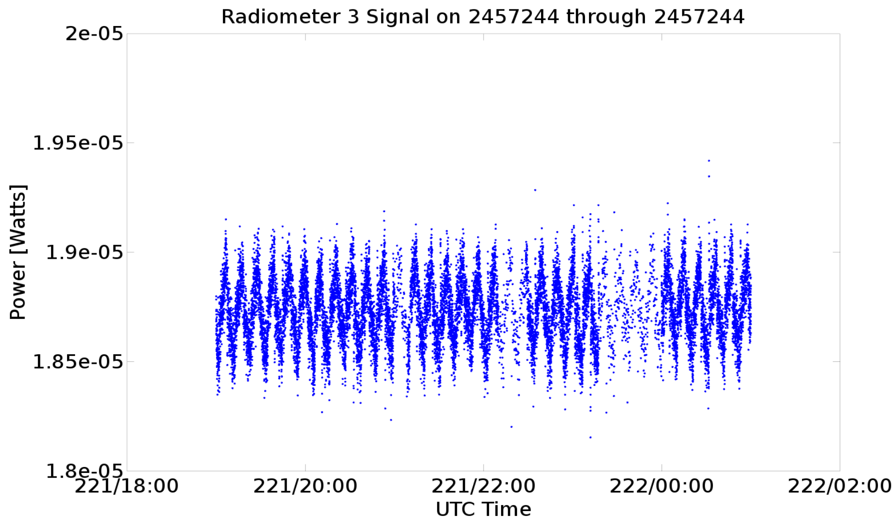

Figure 1: Radiometer Data from DOY 221, 2015 showing data rate switches

The workaround involves two streams of data through Level 1A and 1B processing, the nominal data and the “decimated” data. The nominal data is maintained at whatever the best available data rate is throughout a particular day. The decimated data is forced when needed to the VC1 1/6 Hz data rate by eliminating data points. The sacrifice of data resolution allows for a much more accurate and reliable computation of the demodulation. During Level 1B (L1B), there are corresponding data products for both the nominal and the decimated data sets, see Figures 2 and 3 below.

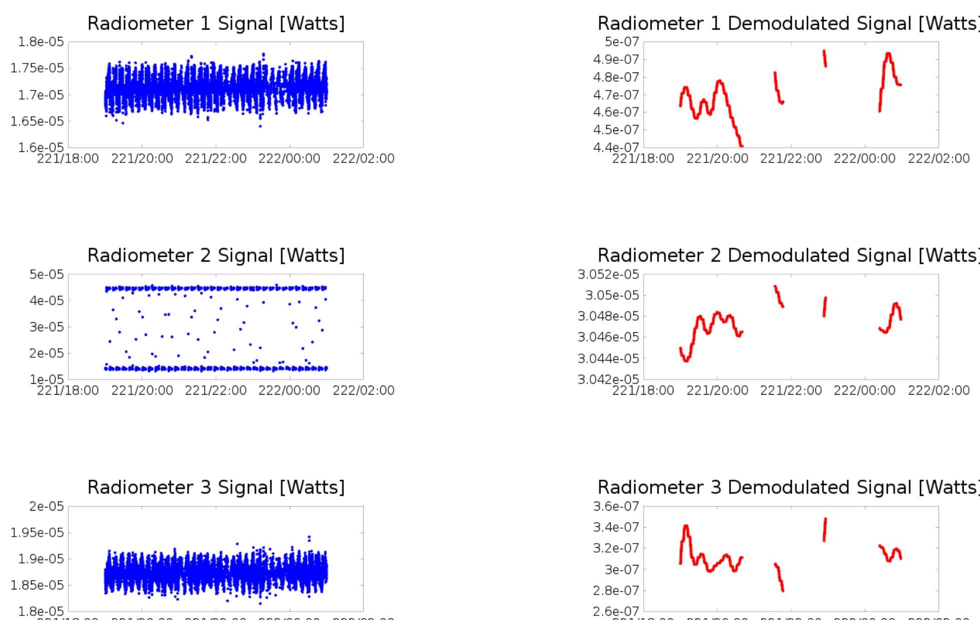

Figure 2: Nominal L1B data products for DOY 221, 2015

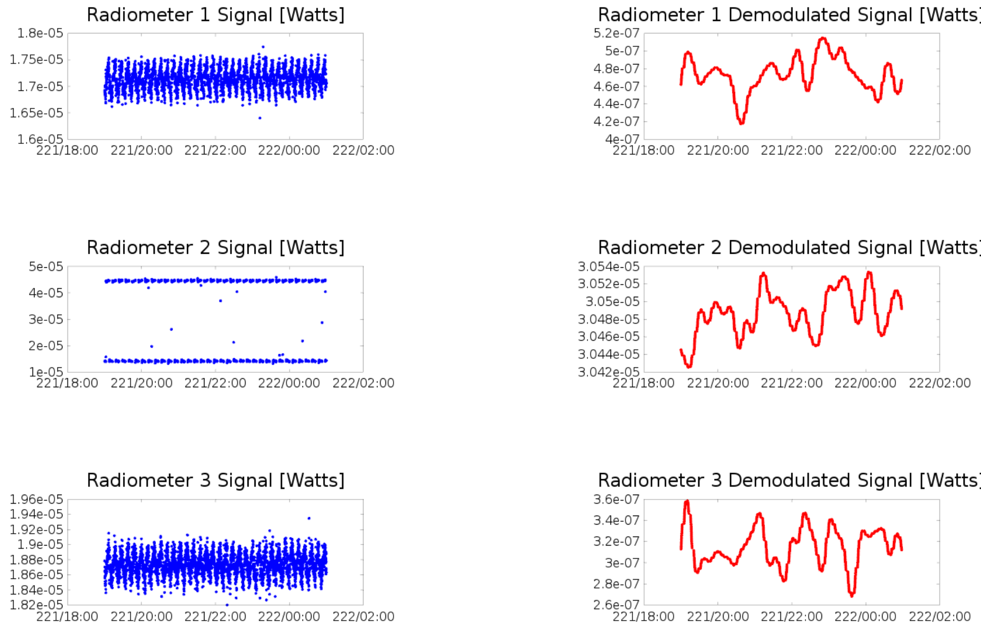

Figure 3: Decimated L1B data products for DOY 221, 2015

II. NISTAR TIMING ANOMALY

An anomaly was first detected by looking at the shutter period. When the instrument was commanded to have a shutter period of exactly ten minutes (600 seconds), the observed behavior was a shutter period which varied and was centered around 638 seconds. A similar ratio was seen when the shutter period was increased to 20, 30, and 40 minutes. This led to an investigation into the discrepancy which revealed a phenomenon referred to as the NISTAR Timing Anomaly. The symptoms of the anomaly are:

- the discrepancy between commanded and observed shutter period,
- 6-8% of science and engineering telemetry is repeated from the previous record,
- science data can be more than two seconds older than the corresponding timestamp,
- engineering data can be more than 20 seconds older than the corresponding timestamp, and
- variability on the observed samples per shutter cycle on the order of the same 6-8%.

The cause of the anomaly is an unreliable 400 Hz clock rate on the NISTAR flight software (FSW). A counter counts down (with respect to the 400 Hz clock) and generates a system interrupt when the counter hits zero. The interrupt callback function adds the period (in the case of science data, 1 second) to the counter and notifies the operating system that a tick occurred. The function will continue adding the period until the counter goes positive (this would occur if a tick was missed and not serviced within the period). In the case of a missed tick, the FSW sees two ticks together but the NISTAR scheduler only learns about one of them. The net effect is that some ticks are dropped entirely (6-8% of the time) and others are serviced irregularly. CompHub (the spacecraft computer) reads NISTAR data at a rate that is closer to 1 Hz. If the data has not been updated by NISTAR, the CompHub essentially re-reads the same old telemetry creating a duplicate.

Correcting the FSW architecture so that the missed ticks are handled by the scheduler is not possible, or at least the risks are too high to make it a practical option. The clock rate is burned into the FSW, and it would have a large ripple effect to attempt rebuilding it. The chosen option was to mitigate the impact through creative ground processing. The most critical impact from the anomalous behavior is that the shutter transitions from open to closed are muddied by the duplicated telemetry. Physically it takes on to two seconds for the shutter to move from open to close, and the duplicated telemetry can report telemetry which is more than two seconds old. The demodulation algorithm of the radiometer signal relies on an accurate knowledge of the number of samples per cycle. The muddied shutter transitions create non-physical noise in the demodulation of the signal unless handled in some special way.

The workaround involves a new algorithm referred to as “manual demodulation”. The algorithm begins as normal, by computing the number of samples per cycle. It then forces the samples per cycle to be one of a hard coded set of possible values, one for each of the operating shutter periods used during the mission: 10, 20, 30, and 40 minutes. Then all the shutter transitions, shutter half-periods, are detected. For thermal reasons, only the latter half of the data for each shutter half-period then are saved to a new radiometer power signal array. Finally the demodulation is done using this new signal which has an absolutely constant shutter period, equal to one half of the original period. It has an additional benefit of only using data which are closer to thermal equilibrium. The result is a piecewise demodulation output which has half of the data missing, but is a much more accurate measurement of the amplitude of the radiometer signal.

III. THERMAL STABILITY

NISTAR computes the irradiance from Earth by measuring the heater power required to maintain a constant temperature in a conical cavity. With the instrument pointed at Earth, less power is required to heat the cavity due to the irradiation from the planet. As this is fundamentally a thermal problem, the measurement is highly dependent on changes to the thermal environment of the instrument.

There are two main operating modes: shutter autocycle on and autocycle off. For the first year of operation, the shutter doors on the radiometers were cycled with a constant period from open to closed, referred to as autocycle on mode. This results in a noisy square wave radiometer power. This signal can be demodulated to find the amplitude of the square wave. The demodulated radiometer power includes the power lost to space from the cavity as well as the actual Earth signal. To isolate the Earth signal, periodic dark space observations are made. The power lost to space is assumed constant whether the instrument is pointed at Earth or dark space. Therefore the difference between the dark and Earth-pointed demodulated power is the actual Earth signal.

The purpose of cycling the shutters is twofold. The demodulation of the noisy square wave signal reduces the noise in the signal by smoothing it out over time. It also makes the measurement robust against drifting of the signal. If the mean of the square signal is slowly changing (possibly due to thermal environment changes), this drift cancels out via demodulation. This is a very nice effect considering the sun angle is always changing, which changes the thermal loading on the instrument.

After months of tweaking parameters to maximize performance, it was determined that operating in this mode would not fulfill the accuracy requirements. This mode made the measurement more resilient to external thermal variation, but revealed another issue: the internal thermal time constant. When the shutter opens, internal components are exposed to the space environment, and cool down. These components, such as the shutters, the filter wheel, baffle tube, etc., are not temperature controlled or monitored. When the shutter closes, these components warm again due to the heat in the cavity. But these temperature swings take time, and to get an accurate measurement of the power required to heat the cavity, thermal equilibrium is needed. Even increasing the shutter period to forty minutes did not allow enough time for full thermal equilibrium. An estimate of the error due to the non-equilibrium state is about 1-3%. Further increases to the shutter period are not practical, because the instrument would miss significant changes to the Earth signal while closed.

Switching to autocycle off mode would completely eliminate the internal thermal time constant issue because the shutters are not moving and changing the thermal loads on the internal components. The trade-off for the switch is that the measurement is more vulnerable to external thermal changes. This is the primary motivation for increasing the frequency of the dark space calibration from monthly to weekly, which is still under discussion. The thermal load on the instrument is affected by various orbital parameters, such as the Earth sun angle, the angle out of the ecliptic plane, distance from Earth and sun, etc. These factors interact and affect the thermal loading in a complex way which cannot be modelled accurately at this time, and likely never will due to the constantly evolving Lissajous orbit path. Therefore we need more frequent dark observations when operating in autocycle off mode to have an accurate offset to extract the Earth signal from the overall radiometer signal.

See the table below which gives results for the previous three dark slews, which all occurred in autocycle off mode, and span about a month in total. There are three sections of results, one for Earth-pointing radiometry, one for dark observations, and the difference between the two is the actual Earth provided signal. Notice in particular the variation in the values of the Earth and dark pointed signals. For example, RC2's dark measurement increased almost 5% from March 18th to April 8th, and another 0.7% from April 8th to April 12th.

Date	3/18/2016 17:00:00	4/8/2016 16:15:00	4/12/2016 15:15:00
Earth	13:39 – 13:59	15:45 – 15:55	14:45 – 14:55
RC1	2.445540E-05	2.807871E-05	2.843201E-05
RC2	4.713700E-05	4.944323E-05	4.973100E-05
RC3	2.488510E-05	2.729266E-05	2.754381E-05
Dark	14:01 – 14:21	16:12 – 16:22	15:12 – 15:22
RC1	2.452018E-05	2.814480E-05	2.852756E-05
RC2	4.757869E-05	4.989750E-05	5.022331E-05
RC3	2.506694E-05	2.747471E-05	2.777625E-05
Difference			
RC1	6.478000E-08	6.609000E-08	9.555000E-08
RC2	4.416900E-07	4.542700E-07	4.923100E-07

RC3	1.818400E-07	1.820500E-07	2.324400E-07

In this case imagine trying to make a measurement of the irradiance on March 28th. We would have a measurement of the Earth-pointed signal on that day, and two dark measurements which were about ten days away on either side and differed from each other by 5%. Some interpolation would be done to find an estimated dark measurement for the day of interest, March 28th, but the science requirement of 1.5% accuracy cannot be hoped to be met in this fashion. On the other hand, an irradiance measurement on April 10th would involve interpolating between two dark measurements that differ by 0.7%, and the accuracy requirement would be very achievable.
Looking at data from the most recent shutter open calibration activity which spanned about ten days, one notices this trend maybe more clearly. Here is one of the radiometer signal plots for that activity:

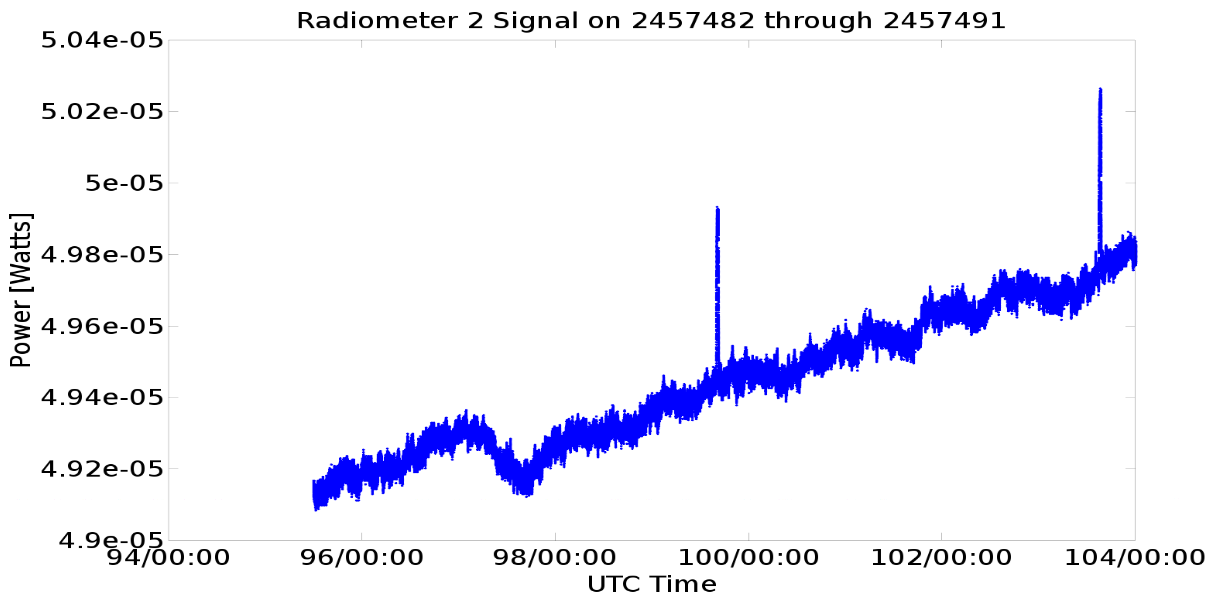

Figure 4: Radiometer Cavity 2 Power Signal for Shutter Open Calibration Activity #3, DOY 95 to 104

There is a significant drift to the signal increasing about 2% from start to finish. The two spikes are the dark space calibrations on DOY 99 and 103 (April 8th and 12th). The dip on DOY 97 is due to the moon coming into the instrument field of regard and exiting it on DOY 98. The drift is due to external thermal changes on the spacecraft. Here is a plot over the same time span of the housing temperature:
Over the same time span the average housing temperature

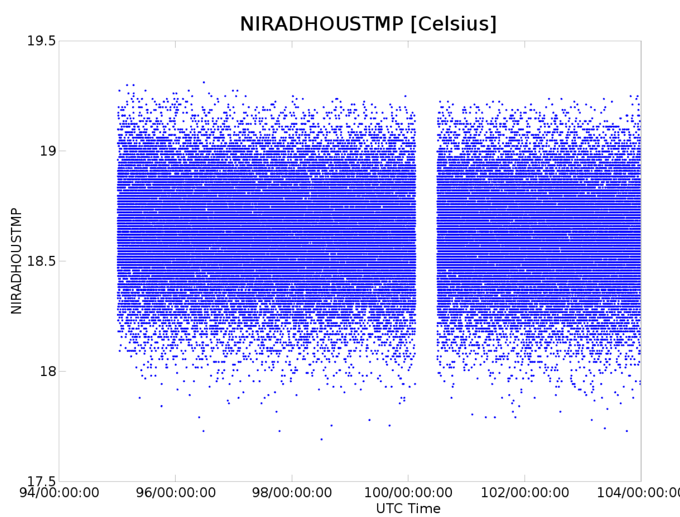

Figure 5: Housing Temperature for Shutter

drifts down by about 0.1 degrees Celsius. For our purposes this is a significant thermal change which manifests into a 2% shift in the heater power requirements. Looking at the ephemeris and orbital data over this time, the sun-Earth-vehicle angle is increasing, the distance between the spacecraft and the sun is increasing, and the angle out of the ecliptic plane is increasing, all of which have the combined effect of cooling the instrument.
For users of NISTAR data relative comparisons of all the autocycle on data is very much still possible, despite the accuracy not expected to be able to meet the science requirement of 1.5%. Seasonal and daily variability measurements have been produced which provide a unique look at the way the planetary albedo changes over time from the vantage point of L1. Now that operations are proceeding in autocycle off mode, the NISTAR science team expects to achieve and surpass the accuracy requirement on the Bands A and B radiometry. Work is underway to model the variability in the heater power with respect to the various temperature sensors on board to help with interpolating between dark space measurements. Note that comparative studies between autocycle on and autocycle off data sets will be difficult to make in some circumstances.

IV. PRECHARGE MNEMONICS

When autocycle is on, the radiometer heaters are controlled and make use of three "precharge" modes: off, fixed, or auto. Precharge in this sense refers to how the heaters handle shutter transitions. When a shutter is about to move from open to closed, it can use the stored precharge values to quickly jump to an expected value for the new shutter position. The motivation is to enable more rapid response to the shutter motions and more rapid achievement of thermal equilibrium.

The three modes operate differently with regards to how these transitions are handled. Precharge off mode, as one would expect, does not use the precharge telemetry and simply allows the heaters to slowly transition from the open value to closed value or vice versa. Fixed precharge mode uses values with are set via command and do not change each shutter period, and can be thought of as open-loop shutter transition control. Auto precharge mode updates the open and closed values each shutter period and is therefore a feedback procedure for handling shutter transitions. Auto precharge is the normal operation mode of the instrument.

In terms of telemetry there are 36 mnemonics of note for this algorithm: NIRC#FOPRECHRG%, NIRC#FCPRECHRG%, NIRC#AOPRECHRG$, NIRC#ACPRECHRG$, and NISPARE*, where # indicate the receiver cavity number (1, 2, or 3), % indicates the band (A, B, or C), $ is either a 0 or 1, and * is a value from 1 to 6. Note the code "FO" indicates fixed open, "FC" fixed closed, "AO" auto open, and "AC" auto closed. The interpretation of the fixed precharge mnemonics is completely as expected and as documented. As an example, the mnemonic NIRC1FOPRECHARGA gives the value which the RC1 heater will be set to when the shutter transitions from closed to open with a band A filter in front of RC1 and fixed precharge mode on. The 17 other fixed precharge mnemonics have similar definitions.

The functions of the auto precharge mnemonics on the other hand are completely nonintuitive. Behavior of the NIRC#AOPRECHRG$, NIRC#ACPRECHRG$, and NISPARE* mnemonics were initially expected to be that $=0 corresponds to filter type A, $=1 corresponds to filter type B, and the NISPARE which follows those two mnemonics in memory/telemetry corresponds to filter type C. This was the case in the original version of the FSW. The observed behavior is that the mnemonics are used independently of the filter type (i.e. all mnemonics are used for each type), and the NISPARE values are correlated with the sum of the values of the $=0 and $=1 mnemonics that precede it under some circumstances. In addition the mnemonics reserved for fixed precharge mode are used to help decide how and where the auto precharge telemetry are stored in a circular memory buffer. The specific details of how all of these data interact are beyond the scope of this report. It suffices to know that in general they work well enough that the correct memory locations are written to and read from when needed. This is all included in this document to illustrate to the user that there is not much useful information to be gained by examining the precharge telemetry on the ground unless one is thoroughly familiar with the control algorithms of the FSW. Also of note, an instrument anomaly occurred which is believed to be a direct result of these algorithms misperforming, and the circular memory buffer getting out of sync.